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Unmanned Vehicle Mission Planning Using 4D Forecasts

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Introduction: We are engaged in the development of mission planning software for autonomous underwater vehicles (AUVs) supporting the Naval Oceanographic Office's underwater glider and AUV programs. Planning missions for underwater vehicles require the consideration of "static" features such as bathymetry, territorial boundaries, and shipping lanes and also time variant features such as water density, sea state, and currents that can be estimated using model forecasts. These myriad considerations result in a 4D × *N* geospatial-temporal constraint satisfaction problem, where *N* is the number of factors and D is typically represented as a value at a specific (x, y, z) location and time t. The difficulty inherent in this decision-making process is the simultaneous manipulation and visualization of these variables, which is accomplished today through human observation of multiple 2D slices of the 4D × *N* cube as shown in Fig. 3. Another complicating factor is the large size of the forecast datasets, which can approach a gigabyte in size.

Geographic Information Systems: Geographic Information Systems (GIS) have been used extensively for 2D × *N* geospatial decision-making and to a lesser extent for 3D × *N* geospatial-temporal decision-making.[1] A goal of this research is to take advantage of the inherent capabilities in standard GIS systems, such as standardized data formats and graphic user interfaces (GUIs), common geospatial databases, multilayered computations, and assimilation of both raster and vector data. CJMTK (Commercial Joint Mapping Toolkit), provided by the Defense Information Systems Agency (DISA) for command and control applications, has become the de facto DoD GIS standard[2] and provides this functionality. However, existing GIS systems have difficulty handling very large datasets and provide little support for 4D visualization. The objective of this research is to develop approaches to the manipulation and visualization of 4D × *N* data within CJMTK that will assist human mission planners with this complex problem.

Decision-making Using Traffic Light Analysis: For the development of software that will assist with the creation of a viable vehicle mission plan that considers environmental influences, it is important to recognize the respective roles and limitations of data visualization and simulation. Essentially, the role of data visualization is to allow the user to create potentially viable mission plans, while the role of simulation is to provide a quantitative analysis of the proposed mission plan using the relevant environmental data. The visualization of 4D × *N* data is inherently limited in that a human cannot readily project where and when a vehicle will be within the 4D × *N* problem space. Consequently, the use of visualization is largely limited to drawing distinctions between regions of the 4D × *N* space that present obvious obstacles and regions in which a mission may be viable.

Traffic Light Analysis (TLA) has been adopted as an approach to helping the human discern "no-go" regions from those in which a specified mission objective may be achievable. Time-invariant 2D fields such as bathymetry provide a straightforward example of this process, where an operator would select a range of acceptable ocean depths for a given mission and the software would visually designate geographic areas that do not meet these constraints as "red." This is illustrated in Fig. 4, where the actual bathymetry (log scale) is shown on the left, and the TLA with a threshold of 200 m is shown on the right. This process becomes slightly more complicated for 4D data, and for this we use a "time-space composite" approach. Figure 5 shows the time-space composite of a time-varying current field, where the thresholds are applied at each location and time within the forecast current data. The final 2D results shown (top, west, and north views) are generated by using an OR operation first to collapse time and then to collapse space in each direction.

Summary: Traffic Light Analysis can be used to help an operator visually display areas within the 4D × *N* problem space that are restrictive based on user-specified parameters. An additional benefit of this approach is a dramatic reduction (on the order of 1:1000) in the amount of data that the GIS software must handle. Even on very large 4D datasets, TLAs can be computed very quickly using fairly simple external programs. With this design, the GIS GUIs are used to identify the data source file and specify the threshold values, but the actual computations would be handled by external programs. Once computations have been completed, the result is loaded into the GIS as a viewable layer, and then GIS functionality can be used on the *N* variables to create a composite multilayer "no-go" region. Developing a mission plan is then a matter of translating mission objectives into a sequence of navigation goals that can be simulated.

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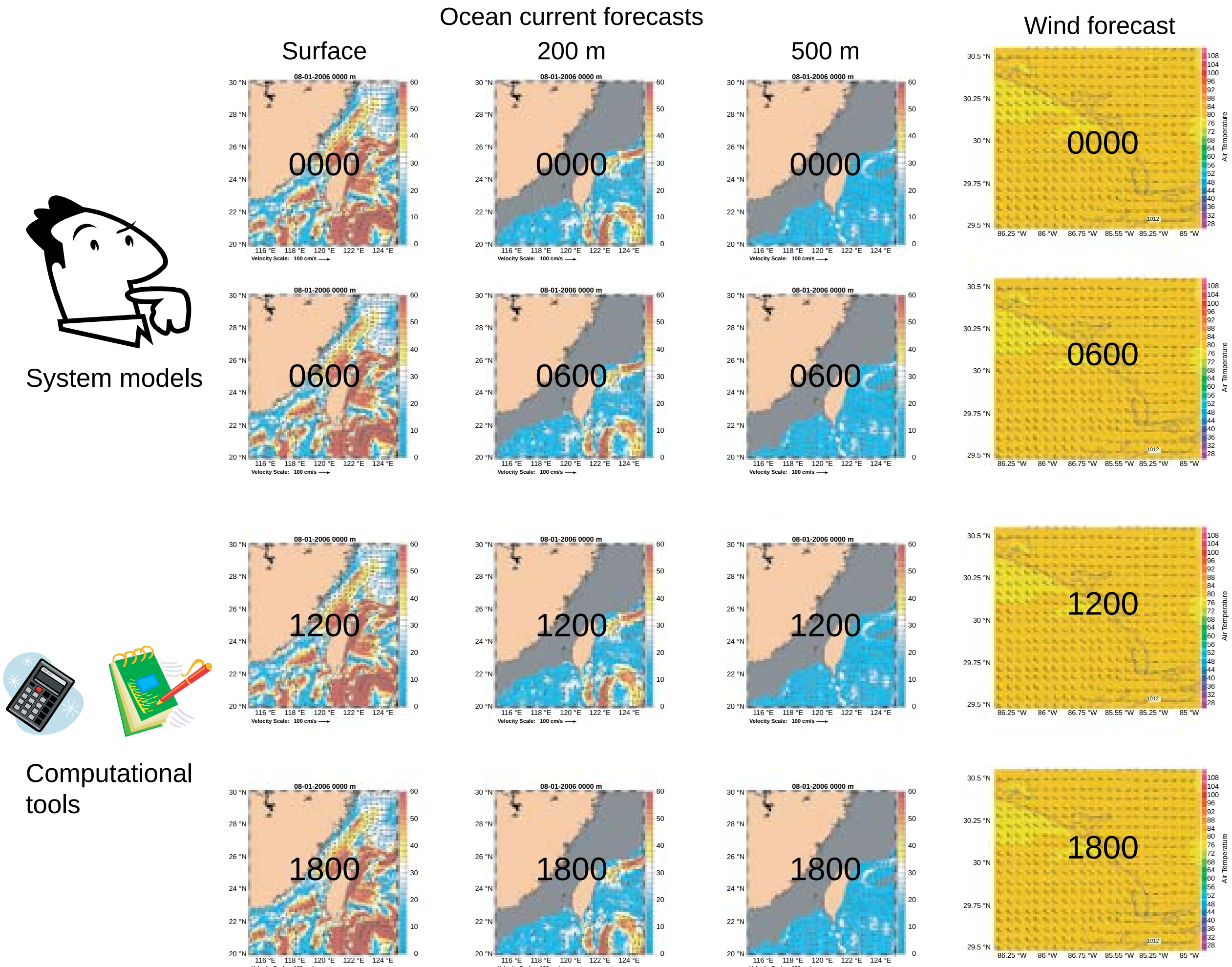

FIGURE 3
This figure depicts the standard approach of trying to visualize the impact of 4D × N variables by displaying individual 2D slices of each variable over time. Ocean current would require an x, y slice at each depth of interest for each time interval of interest. 2D plots could be used to show forecast weather, but if winds at different altitudes were also a consideration, then 2D slices for each altitude of interest would be needed at each time interval. For lack of adequate geospatial software to assist with this process, the computational tools used are all too often a calculator and a note pad. Without the assistance of software that can manipulate this data, creation and optimization of mission plans that consider all of these variables is left to the mind of an experienced operator. While the human expert offers a significant ability to mentally process this information, the result typically lacks numeric and quantitative analysis of alternatives.

References

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[2] S. Riley "A Shared View of the Battlespace," *C⁴ISR* **5**(2), March 2006, www.C4ISRjournal.com.

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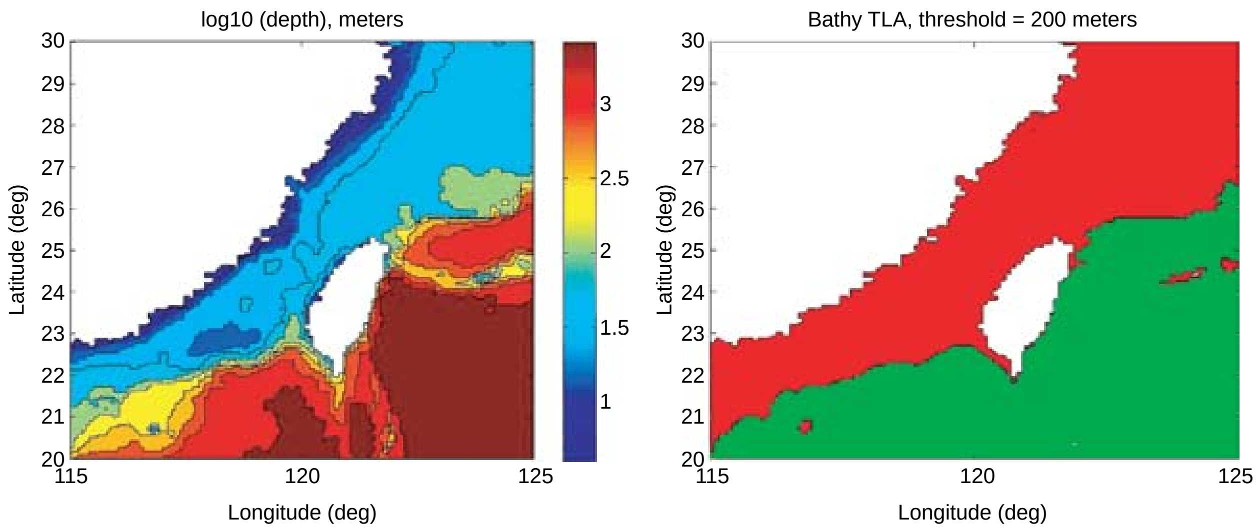

FIGURE 4
The bathymetry data (logarithmic scale) in the area of interest is shown on the left. The Traffic Light Analysis (TLA) of this data, using a specified threshold of 200 m, is shown on the right. The red indicates the geographic area, based on the user-specified threshold, in which it would be unacceptable to operate a particular vessel.

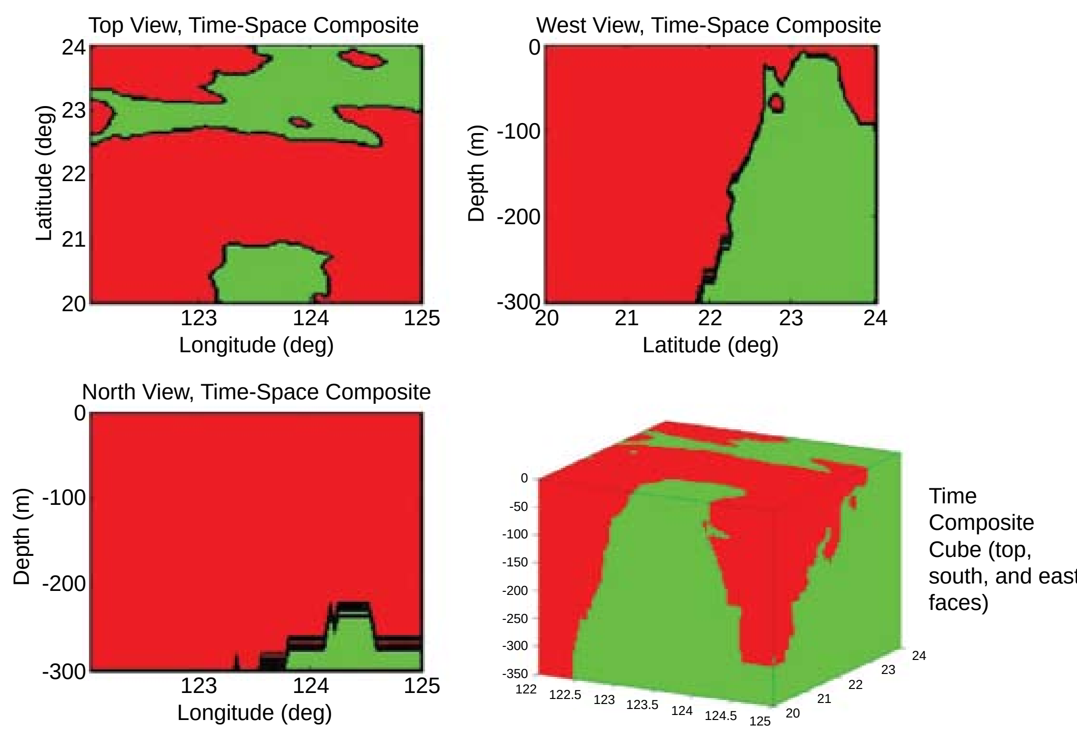

FIGURE 5
This figure shows the result of a “time-space composite” TLA. The time composite operation results in a 3D cube that is shown on the bottom right. This is generated by flagging as red all locations within the cube that violate a user-specified threshold at any time. The top, north, and west 2D time-space composite results shown are each generated by doing a similar logical OR operation perpendicular to the indicated plane. The red areas are different on the faces of the cube than on the 2D time-space composites since the time-space composite will show red if any location in the cube “below” each (*i,j*) position violates the threshold. The resulting time-space composite views will necessarily represent the most conservative application of the threshold, but if the remaining non-red regions are sufficient to accomplish mission objectives, the operator can proceed to specifying a mission plan and then simulation. Numerous time-space perspectives can be generated by using average, maximum, and other basic mathematical functions. For example, a station-keeping mission might use the average to indicate the net motion of the water mass over time.